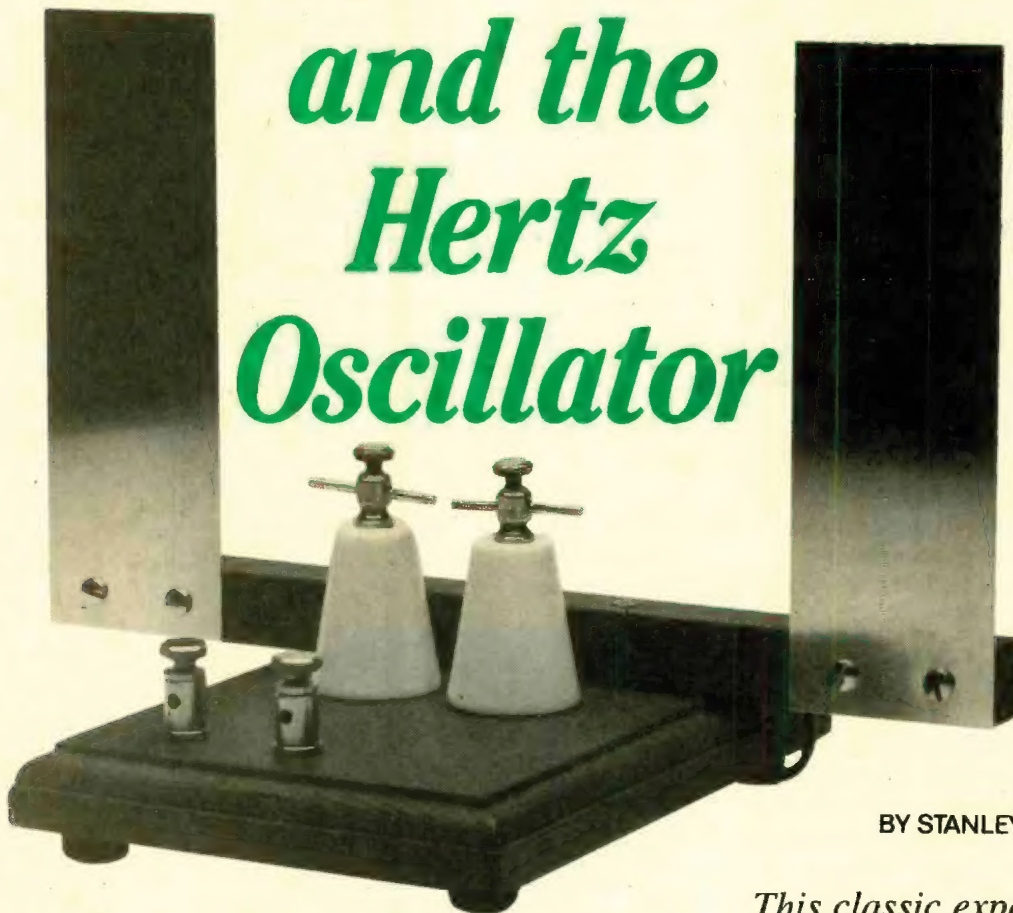


Electric Waves and the Hertz Oscillator



BY STANLEY A. CZARNIK

This classic experiment by Heinrich Hertz proved Maxwell's theory of electromagnetic waves.

By the middle of the 19th century, certain regularities in the behavior of electricity were becoming obvious to experimenters everywhere. Following the work of Coulomb, Oersted, Ampere, Faraday, and others, it was clear that an electric current created a magnetic field, that a magnetic field in motion near a conductor created a current, and that a current in one circuit could induce a current in another circuit. It was also known that electric charges attracted and repelled each other according to a law similar to the one associated with gravitation (the inverse square law).

But questions remained. For example: How did the electric and magnetic forces move through space? One popular explanation involved the analogy between electricity and gravitation. Theorists imagined a charge (or mass) located at one point exerting an instantaneous influence on another charge (or mass) at some

other point. No manifest connection had to exist between the two points. This old and somewhat mystical idea was known as "action at a distance."

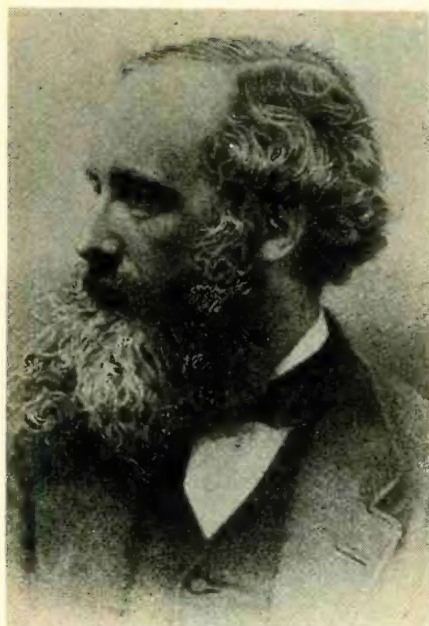
Another theory was suggested by Michael Faraday. He postulated about "lines of force," the kind made visible by sprinkling iron filings on a sheet of paper placed over a magnet. The idea of lines of force stimulated the interest of another Englishman, James Clerk Maxwell, one of the greatest mathematical physicists ever. Ultimately, that interest was to become a theoretical representation of the electromagnetic wave.

The evolution of Maxwell's thinking on the matter passed through a number of preliminary phases and is (as it always was) quite complicated. The following should be considered only a very short summary of the points relevant to the rest of our story.

It had been known for a time that localized electrical activity occurred in insulators, like the air in a Leyden jar

capacitor. Maxwell was the first to suggest that a current moving through such an insulator was a current of a special kind. He called it a displacement current. The reasoning ran like this: If an electric force applied to a dielectric (like air) was varied continuously, the result would be a wave of electric displacement. The periodic displacement wave would be accompanied by a periodic magnetic force. When the two were taken together, the result was an electromagnetic wave.

Next, the question of velocity came up. By the middle of the 19th century, the speed of light was known both from astronomical observations and from direct terrestrial experimentation. In 1849, Hypolyte Louis Fizeau calculated it by using a rapidly rotating toothed wheel and a mirror to reflect the light back to the wheel. Since the light was blocked by one of the teeth on its return journey, the speed of light could be calculated from the size and



James Clerk Maxwell (1831-1879) was the first to formulate a consistent mathematical representation of electromagnetic waves.

spin of the wheel and the distance of the mirror.

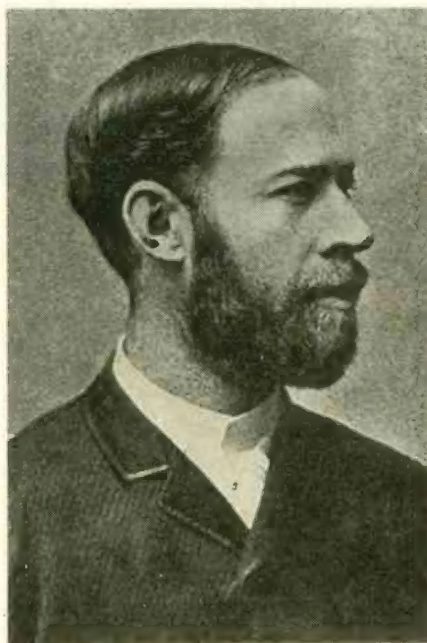
Now, following the work of Wilhelm Weber and Friedrich Kohlrausch on the speed of an electric disturbance along a wire, Maxwell was able to calculate the velocity of displacement currents in a dielectric. The numbers corresponded closely with those obtained for the speed of light.

The scientist pressed ahead to what was, for him, the obvious conclusion: the fundamental identity of electrical disturbances and light. As he phrased it: "light consists in the transverse undulations of the same medium which is the cause of electrical and magnetic phenomena." The idea was developed further and acquired a formidable mathematical representation in the important paper "A Dynamical Theory of the Electromagnetic Field" published in 1864.

Heinrich Hertz. Maxwell's electromagnetic theory was expressed as an arrangement of equations. But just what sort of physical system might correspond to the mathematical constructions was not clear. He failed to provide a circuit capable of generating the electromagnetic waves. Maxwell's model was difficult to visualize and the lack of experimental verification created a certain skepticism among many of Europe's leading physicists.

The experimental illustration of the electromagnetic theory did not come until 1888, nine years after Maxwell's early death at the age of 48. The necessary electrical apparatus was put together by a young German scientist, Heinrich Hertz.

Heinrich Rudolf Hertz was born in Hamburg, Germany, on February 22, 1857. His family was both cultured and prosperous; he had three younger sisters and one younger brother. Hertz's practical skills became evident at an early age. By the time he was twelve, he had wood-working tools and a workbench. Later, he obtained a lathe and used it to build various physical instruments. His paternal grandfather studied natural philosophy and had a small private laboratory. While still in his boyhood, Hertz was able to acquire some of his ancestor's scientific equipment.



Heinrich Rudolf Hertz (1857-1894) provided a reproducible experimental illustration of Maxwell's theories. The work was carried out in a lecture hall at the Technische Hochschule at Karlsruhe, Germany, in 1888.

Hertz studied at the University of Munich and then at the University of Berlin, where he came under the influence of the great German physicist, Hermann von Helmholtz. After completing his education, Hertz took a teaching position at the University of Kiel in 1883. It was at Kiel that Hertz found the time to make his first deep study of Maxwellian electrodynamics.

Like many of his contemporaries,

Hertz found Maxwell's ideas and equations hard to understand. Indeed, at one point, the unusual mathematical difficulties nearly forced him to give up all hope of forming any consistent conception of Maxwell's models. But he persisted. In the spring of 1884, he wrote in his diary: "Hard at Maxwellian electromagnetics. Nothing but electromagnetics. Hit upon the solution to electromagnetics this morning."

Further Reading

The Identity of Light and Electricity, Heinrich Hertz, *Popular Science Monthly*, Volume 38 (December 1890): pages 179-188.

"Some Possibilities of Electricity," William Crookes, *Fortnightly Review*, Volume 52 (1892): pages 173-181.

Electric Waves, Heinrich Hertz, Macmillan, 1893

Pioneers of Electrical Communication, Rollo Appleyard, Macmillan, 1930.

"Action at a Distance in Classical Physics," Mary Hesse, *Isis*, Volume 46 (1955): pages 337-353

"James Clerk Maxwell," J.R. Newman, *Scientific American*, Volume 192 (June 1955): pages 58-71.

"Heinrich Hertz," Philip and Emily Morrison, *Scientific American*, Volume 197 (December 1957): pages 98-106. ■

The school at Kiel had no physics laboratory. So, when Hertz was offered a professorship at the *Technische Hochschule* at Karlsruhe, with its well-equipped Physical Institute, he accepted. Hertz found some high-voltage induction coils in the equipment collection. The transformers were just what he needed to build a real, working, experimental illustration of Maxwell's theories.

Given the complicated mathematical symbolism which inspired it, the extreme simplicity of Hertz's oscillator system is remarkable. This is what he did. He connected a strong battery of Bunsen cells to the primary windings of an induction coil equipped with a mercury interrupter. The secondary of the coil was attached to two large spheres or plates of zinc mediated by a spark gap. The two large conductors amounted to a radiating dipole antenna. In a sense, the two conductive ends of the Hertz's dipole

were actually the inner and outer foils of a disassembled Leyden jar. There was no ground connection. For a detector or resonator, Hertz used a simple loop of wire the ends of which were separated by a very small spark gap.

The Experiment. Hertz set up his novel oscillator at one end of the Karlsruhe lecture hall; the resonator was placed at the opposite end. The room lights were extinguished and the scientist permitted his eyes to become accustomed to the dark. When the transmitter was switched on, a series of tiny electrical flashes became visible at the spark gap of the resonator.

Here were the electromagnetic waves he wanted. But, how fast were they moving? Hertz had no oscilloscopes or electronic test equipment of any kind, so direct measurements were impossible. Instead, he worked with the wavelengths. He set up a sheet of zinc against a wall to reflect the signals. Then, by studying the patterns of interference between the waves going out and the one coming back, he was able to calculate the wavelength and finally the speed of propagation. Hertz found no evidence for the mysterious and instantaneous action at a distance. The velocity of the waves was not infinite; it was finite; it was the speed of light.

The young physicist had verified a very difficult theory with a very simple demonstration, and the illustrative power of the experiment cannot be over-estimated. Hertz phrased it like this: "There are many friends of nature interested in the problem of light who are capable of comprehending simple experiments, but to whom Maxwell's theory is still unintelligible."

The Project. With an induction coil, low-voltage DC power supply, and a few scraps of wood and metal, you can build a functional replica of the Hertz oscillator and transmit electromagnetic signals to an ordinary AM radio. Like Hertz's original construction, the unit makes use of no electronic components whatsoever. The system goes together quickly; for those of you who have not yet worked with high-voltage apparatus, the beautifully simple Hertz oscillator is an excellent place to begin.

The cylinder-shaped high-voltage transformer shown in the photograph has been featured in this magazine before (June 1989 and March 1990); the earlier article also appears in the 1990 edition of the Electronics Hobbyist Handbook. It's an automobile ignition coil plus interrupter and runs on about 12 volts.

The particular unit shown, to the best of my knowledge, is no longer available on the regular commercial

PARTS LIST FOR THE HERTZ-OSCILLATOR EXPERIMENT

AM radio

Binding posts (4)

DC power supply, low-voltage

Induction coil (see text)

Porcelain insulators, or equivalent (2)

Narrow metal rods (2)

Rubber feet (4)

Brass or aluminum sheet metal, 2 × 6 inches (2 pieces)

Telegraph key, or equivalent

Wooden block, 5 × 7 inches

Wooden stick, 10 × 3/4 inches

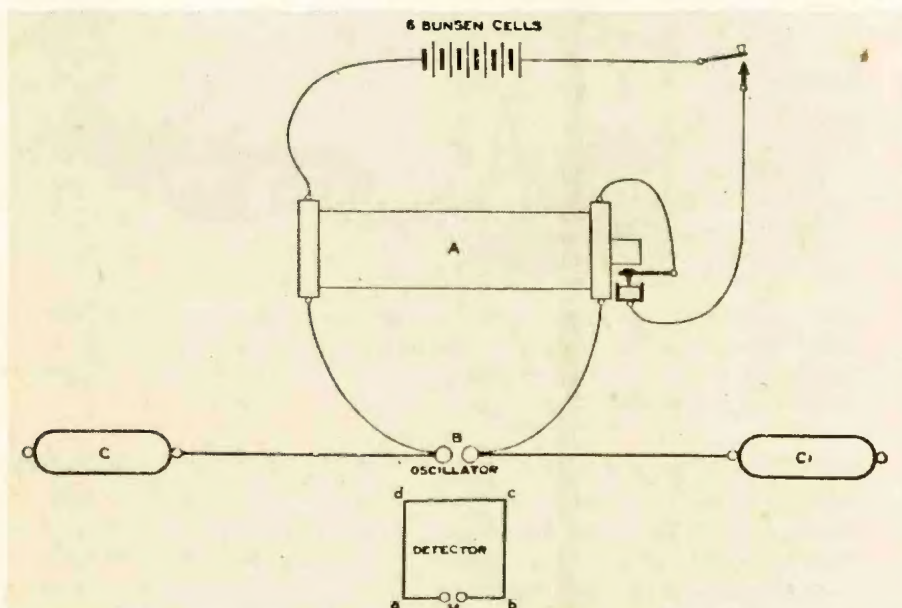
Wood screws, machine screws, threaded rod, solder, soldering lugs, hook-up wire, etc.

Induction coils, enclosed in a hardwood box and equipped with an adjustable vibrator mechanism, are available from Fisher Scientific, Educational-Materials Division, 4901 W. LeMoine Street, Chicago, Illinois 60651 (Telephone: 1-800-621-4769, or, within 312 area code, 378-7770. The catalog number is S-43525 and the price is \$112.00. Add \$5.00 for shipping and handling. IL residents must add appropriate sales tax.

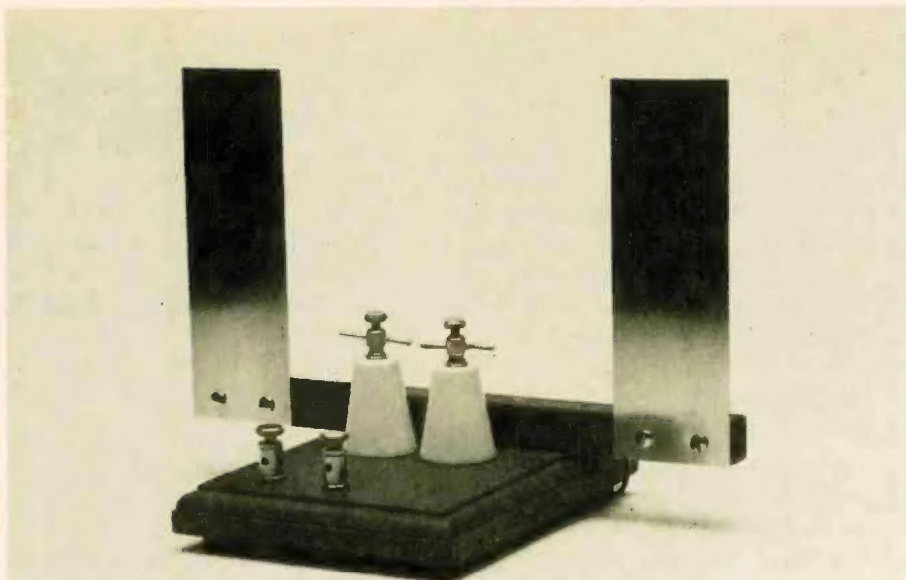
market. However, almost any high-voltage induction coil equipped with low-voltage DC input terminals and a make-and-break vibrator mechanism will work just fine. Coils of this type are currently available from Fisher Scientific, a laboratory supply company, in Chicago; see the Parts and Materials List for more information. The coil from Fisher is a bit more powerful than the typical auto ignition unit.

Construction. Obtain a block of wood about 5-inches wide, 7-inches long, and 3/4-inch thick. Somewhere near one of narrower ends of the block, drill two holes for the input terminals. Remember that this device runs on high voltage; do not place the input terminals too close together. The space between the binding posts should be somewhat larger than the maximum size of the spark available from the induction coil.

The appearance of the oscillator is improved by doing all of the wiring on the underside of the baseboard so now might be a good time to attach four small rubber feet to the bottom of the block to provide space beneath



Given the complicated mathematical symbolism that inspired it, the extreme simplicity of Hertz's electromagnetic oscillator is remarkable. The high-voltage output of an induction coil (A) is connected to a radiating dipole antenna (C and C'), the two parts of which are separated by a spark gap (B). For a resonator, Hertz used a loop of wire (a, b, c, and d), the ends of which form a very small spark gap (M).



The oscillator described in this article is similar to the original built by Hertz over 100 years ago. A dipole antenna made of two metal sheets is connected in parallel to a spark gap and a pair of high-voltage input terminals. The unit measures 7 inches high, 10 inches wide, and about 7 inches long. The wooden base and crossbar have been stained.



The size of the oscillator spark gap depends in part on the power of your induction coil. A small coil will call for a $\frac{1}{8}$ - to $\frac{3}{8}$ -inch air break. A larger coil may require more space. The spark gap terminal posts should be at least $1\frac{1}{2}$ -inch apart.

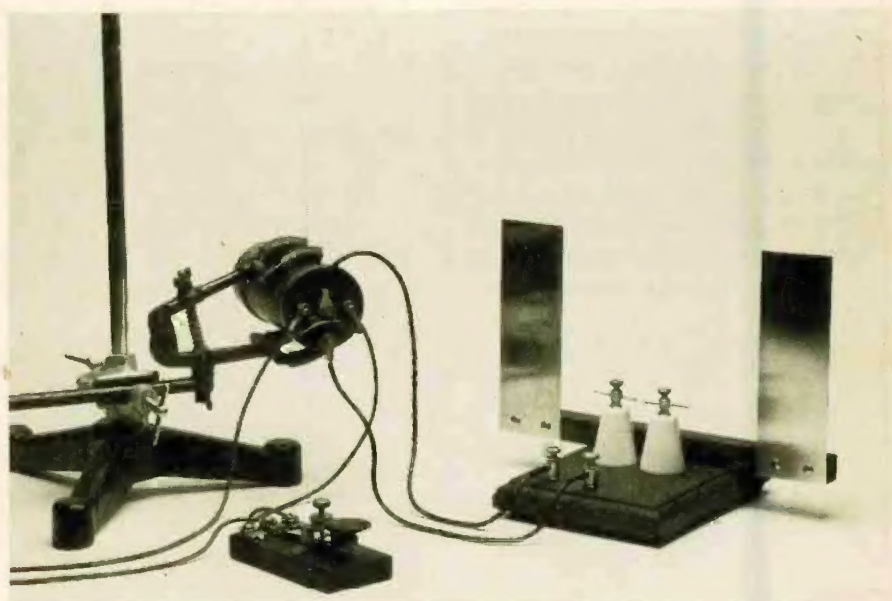
the wood for the necessary connections.

Next, somewhere near the center of the block, drill two holes for the oscillator spark gap. Those holes should be at least $1\frac{1}{2}$ -inch apart. A very powerful induction coil may require a still larger separation.

The size of the spark gap must be to some extent adjustable. The easiest way to do that is with two short metal rods held in place by a couple of small binding posts. The spark gap in the photographs is mounted on a pair of old-fashioned porcelain insulators. I just happened to find a few, covered with dust, sitting on a shelf in my workshop; perhaps you can locate something similar. The arrangement is fastened to the baseboard with two

threaded rods cut to the proper length and furnished with soldering lugs.

Now you'll need two rectangular



Here's one way of setting up your electromagnetic wave generator system. The low-voltage input to the induction coil is controlled with a momentary switch, in this case, a telegraph key. The high-voltage output goes directly to the oscillator. The circuit requires no ground connection.

sections of brass or aluminum sheet metal for the dipole antenna. Small pieces of sheet metal are often available at certain large hobby shops. Each piece should be about 2-inches wide and 6-inches long. Drill two small holes near one narrow end of each piece. Next, obtain a piece of wood about 10-inches long and $\frac{3}{4}$ -inch

square. Drill two holes near each end of the stick to match the holes in the metal rectangles. Attach the metal to the wood with machine screws. Don't forget to equip each side of your antenna with a soldering lug. Fasten the antenna to the baseboard with a couple of wood screws as shown in the photographs.

Finally, warm up your soldering iron, locate some heavy-gauge insulated hook-up cable, and wire up the oscillator. The high-voltage input terminals, the spark gap, and dipole antenna are all connected in parallel. Make certain that all wires are kept as far away from each other as possible. If the wires get too close, you are liable to wind up with an unwanted spark gap underneath the oscillator.

Operation. Locate your induction coil and connect the primary windings to an appropriate DC power supply. Most induction coils run on about 6 to 12 volts. The low-voltage input circuit should be provided with some sort of momentary switch; a tele-

graph key is ideal. Next, set the oscillator spark gap to a distance of about $\frac{1}{4}$ inch. With a very small coil (like the one in the photograph), the best operational gap may be even smaller. With a larger transformer the distance may have to be increased. Finally, connect the high-voltage sec-

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ELECTRONIC WAVES

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ondary of the coil to the terminals of the oscillator. Keep the low-voltage input wires at least 1 or 2 inches away from the high-voltage output cables. The system requires no ground connection.

Obtain an ordinary AM radio, turn it on, and set the tuner to almost any stationless position on the dial. Place the radio anywhere within several feet of the oscillator. Now, switch your system on and depress the telegraph key. You will hear a loud, scratchy, static buzz over the radio as sparks leap across the gap on the oscillator. If the radio doesn't buzz or if the sound is very weak, the oscillator spark gap is probably too big. A word of warning: **do not** under any circumstances attempt to adjust the spark gap when the oscillator is running.

Set the radio to some other place on the dial. When you press the key, you will still hear the buzz. That happens because the Hertz oscillator is not transmitting on a single frequency. The electromagnetic radiation you're

producing does not take the form of a smooth, continuous wave. It's a series of pulses, each of which consists of a highly damped sinewave. In a pulse of that kind, the amplitude of each successive oscillation is smaller than the amplitude of the preceding one. Typically, the decrease follows a logarithmic pattern.

A tiny modification will allow you to actually see the electromagnetic signal as well as hear it. Obtain a small fluorescent tube and lay it down within 3 or 4 inches of the oscillator's dipole antenna. Place the tube so that its length is parallel to the flat surface of the two upright metal sheets of the dipole. (If the tube is placed in a perpendicular position, you may not get the effect you're looking for.) Now, when you operate your oscillator, the tube will flash!

Once again, do not touch the oscillator when the system is in operation, the entire unit is alive with high-voltage; if you make contact with any of the conductors, you will receive a strong and possibly dangerous electric shock. So, please be very careful when performing this experiment.

Conclusion. Heinrich Hertz is sometimes credited with the invention of the first primitive system of wireless communication, i.e., spark telegraphy. But that perception is actually a reflection of our modern historical vantage point in place of his own. Hertz never devoted a lot of attention to the practical potentials of electromagnetic-wave technology. The reason for that is clear. What Hertz was after from the very beginning was experimental proof of Maxwell's theories and a refutation of the theories of instantaneous action at a distance. The creation of a new type of communications device was never his goal or a part of his plan.

Of course, it didn't take long for other natural philosophers to begin thinking about things to come and the implications of Hertz' experiment. One such person was that master of speculation and Victorian visionary, William Crookes. In 1892, he wrote: "Here is unfolded to us a new and astonishing world—one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence." ■